Successful hybrid approach to visual and video observations of the 1999 Leonid storm

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A new hybrid technique of visual and video meteor observations is described. The method proved particularly effective for airborne observations of meteor shower activity. Results from the 1999 Leonid Multi-Instrument Aircraft Campaign are presented, and the profile shape of the 1999 Leonid storm is discussed in relation to meteor shower models. We find that the storm is best described with a Lorentz profile. Application to past meteor outbursts shows that the current multi-trailet model of a dust trail is slightly shifted and we crossed deeper into the 1899 epoch trailet than expected.

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1. Introduction.

The requirement for near-real time flux measurements from aircraft has led to the development of a hybrid technique of visual and video meteor observations. The method has a team of visual meteor observers view the video output of intensified cameras using video head displays (Fig. 1). The cameras are mounted behind optical windows, pointed at relatively low altitude. The cameras make it possible to conveniently observe part of the sky with a well defined field of view. Last year, during the 1998 Leonid MAC mission [1], we discovered that meteor rates are highest near the horizon [2]. We further boost the meteor count by visually inspecting the tapes rather than using automatic detection software programs. The results enable a precise analysis of the 1999 Leonid storm rate profile.

2. The method.

During the 1999 Leonid MAC mission, a team of eight visual observers first demonstrated this new approach onboard the "*Advanced Ranging and Instrumentation Aircraft* (ARIA)", operated by the USAF/452nd Flight Test Squadron.

A counting tool was developed that records the detection of Leonid shower or sporadic meteors with the click of a mouse button. The tool has six entrance ports, which recorded the counts from one of six different intensified cameras. The four cameras considered here had a field of view of 39° x 29° and where mounted at an elevation of 22° behind BK7 optical glass windows.

Figure 1 - Observer Jane Houston with video head display.

Each observer was assigned a mouse bearing a unique machine-readable identification number; each camera had its own designated computer port. The mice were chosen for their ergonomic design and their light-response buttons. The observer began each observing session by plugging the mouse into the computer port corresponding to the camera being used by the observer; the mouse was unplugged at the end of each viewing session. This permitted the computer to identify the starting and ending times of each viewing session, and determine which observer was watching from what camera at all times. Rotating the observer/camera pairings enabled calculation of individual observer and camera coefficients of perception from systematic differences in the counts.

During the 1999 Leonid meteor storm, ARIA flew from the UK to Israel, from Israel to the Azores, and from the Azores to Florida in three consecutive nights. The peak of the storm occurred while enroute from Greece to Italy. Near-real time flux measurements were automatically transferred to a communication station onboard the aircraft, where the counts were send to NASA/Ames Research Center by e-mail, telephone or direct internet access using INMARSAT satellite telephone lines. From NASA/ARC, the counts were further distributed to operation centers, such as the NASA and USAF sponsored LEOC at Marshall Space Flight Center and ESA's orbital debris center at ESOC, Darmstadt.

Shortly after the mission, several observers gathered at NASA/Ames Research Center to view in the same manner the video tapes that were recorded by four similar intensified cameras onboard the twin "*Flying Infrared Signature Technology Aircraft* (FISTA)" during the peak night, about 150 km from ARIA.

3. Results

A total of 33,000 video Leonids were recorded in this manner, which accounts for about 3/4 of all Leonids on video. This compares with 277,172 Leonids that were observed by 434 visual observers worldwide and gathered by the International Meteor Organisation [3]. Both data sets will be discussed together. The video data will be shown by black points, the previously published visual data by open squares. Although the number of video meteors is 8 times less than the visual record, the measurements are performed under much better controlled conditions, from which a more precise result can be expected.

Figure 2 shows the peak of the storm. Individual points are 1-minute intervals. No smoothing was applied. Each interval is an independent measurement. The video data are very smooth. The curve is featureless. A small depression at the peak can not be trusted because it is not present in the ARIA and FISTA data in the same way. We suspect that muscle fatigue in the button-pressing fingers started to become a problem at about that time. In hindsight, it appears that the technique works well for rates between ZHR = 5 and 5000, but the technique will need modifications to conveniently cope with higher rates.

In this paper, our video rates are scaled to the visual Zenith Hourly Rates calculated by Arlt et al. [3]. Arlt's rates represent independent intervals of 2.8 minutes. We are not concerned with the absolute values, but with the shape of the curve. Hence, all data are plotted on a logarithmic scale, so that any scaling is a mere shift in the graph. It is a compliment to visual and video observers to see how well both datasets agree! The peak is confirmed at solar longitude $\lambda_o = 235.285 \pm 0.001°$, or about 02:02 UT.

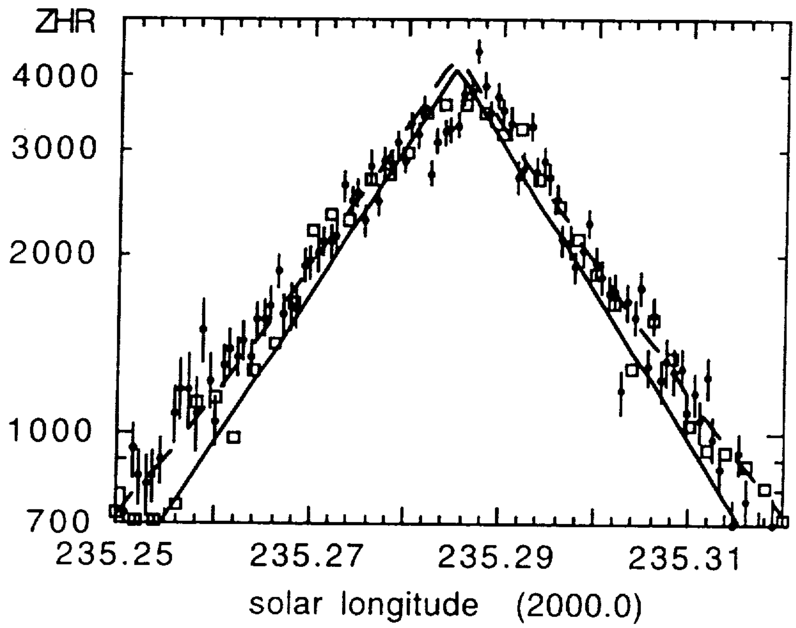

Figure 2 - The peak of the 1999 Leonid storm. Open squares are data from [3]. The solid line shows the storm component (main peak), while the dashed line is the sum of all components.

We do not confirm "additional clear enhancements [3]" in the visual rate profile, which Arlt et al. were quick to assign to features in shower models. These are probably the result of imperfect corrections for observer perception, observing conditions or other factors that affect visual observations. For the same reason, the features in the profiles from individual locations in [3] can not be trusted. In the remainder of the paper, we will concentrate on the gross features of the curves that are confirmed by both video and visual results.

When plotted on a logarithmic scale, as in Fig. 2, it is clear that the slopes of the storm peak are linear and well represented by an exponential equation like [4]:

$$ZHR = ZHR_{max}\ 10^{-B\,|\lambda_o - \lambda_o^{max}|} \qquad (1)$$

From a least squares fit, we find B = 24±2 per degree solar longitude for ZHR larger than 700. A slightly larger B = 25±1 value (and ZHR_{max} = 4100 per hour) results when a composite of such curves is fitted to the profile that also accounts for other more shallow features. This value is slightly less than the B=30±3 derived from the 1866, 1867, 1966 and 1969 Leonid storm profiles [4], when Earth crossed deeper into the respective trailet.

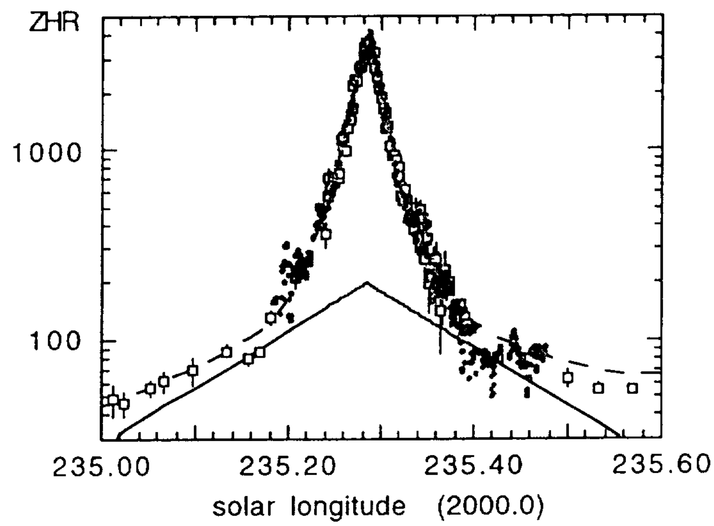

Figure 3 - Background to the main peak.

Above solar longitude λ_0 = 235.38 (and below 235.20), rates level off significantly in both video and visual data (Fig. 3). A similar background structure to the main peak was observed in the 1866 and 1966 profiles [4]. The slopes are near linear again on a logarithmic scale, with B = 2.5 ±0.2. Combined with other components, we have B = 3.0±0.3, slightly less than found before (B = 4-6 [4]). This structure appears to be centered within 0.01° from the center of the storm peak, and has ZHR_{max} = 200±10.

From the visual data [3], we conclude that the magnitude distribution index does not seem to change over the peak. This implies that the magnitude distribution index of the background component and main peak are the same (as we concluded earlier from the 1866 and 1966 profiles [4]). And that suggests strongly that both components are part of one and the same profile. We may be able to verify that from the video record in the future, but will take this as a fact for the remainder of the paper.

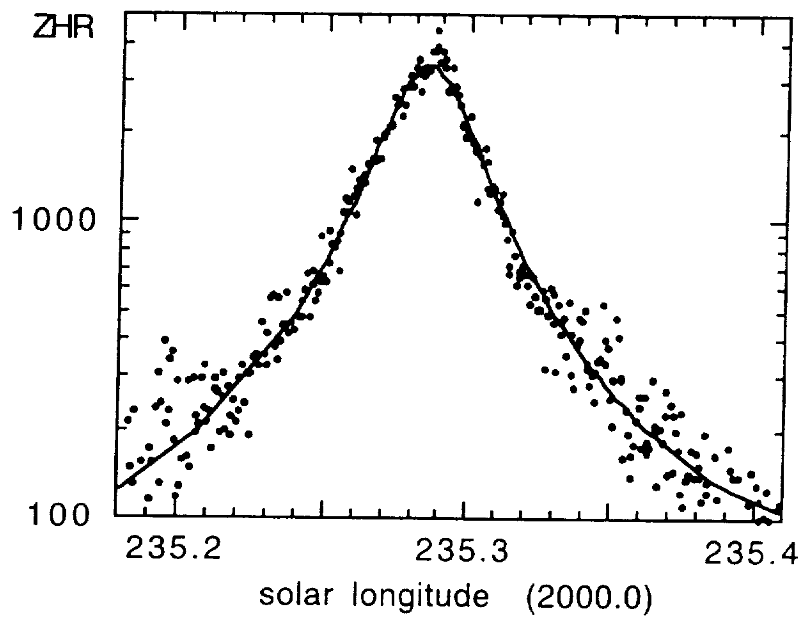

Figure 4 - Fit of a Lorentz profile to the meteor storm profile. For clarity, error bars are not shown.

4. Discussion.

In the past, shower profiles have been described in terms of Gaussian and exponential shapes [3]. Now, we find that the Lorentz profile, known from damped oscillators, has a shape very similar to the peak and background combined:

$$ZHR = ZHR_{max} \frac{(W / 2)^2}{(\lambda_o - \lambda_o^{max})^2 + (W / 2)^2} \qquad (2)$$

W is the classical width of the profile at half the peak intensity (in degrees). Indeed, the main peak above ZHR = 300 is best fitted with a Lorentz profile of width W = 0.036±0.002° and ZHR_{max} = 3300±100, the line shown in Fig. 4. Even if we ignore the background component, the tail of the curve falls right on when the peak is fitted.

Past meteor storms show a similar good fit, which implies that each dust trailet itself has a Lorentzian cross section. If the dust distribution in a trailet follows a lorentz function as a function of r = distance from trailet center, then:

$$ZHR(r) = ZHR'_{max} \frac{(W_t / 2)^2}{(r - r_{max})^2 + (W_t / 2)^2} \tag{3}$$

In that case, if we pass the center of the trailet at a distance $Y = Y_o$ (measured in a direction perpendicular to Earth's orbit), then the cross section is still a Lorentzian:

$$ZHR(\lambda_o) = ZHR_{max} \frac{Y_o^2 + (W / 2)^2}{(\lambda_o - \lambda_o^{max})^2 + Y_o^2 + (W / 2)^2} \tag{4}$$

where the width of the dust trailet (Eq. 3) equals:

$$W_t = Y_o^2 + (W / 2)^2 \tag{5}$$

and the peak rate in the trailet is:

$$ZHR'_{max} = ZHR_{max} \frac{Y_o^2 + (W / 2)^2}{(W / 2)^2} \tag{6}$$

This condition is necessary to account for the fact that we passed the dust trailets at different distances from the center in 1999, 1966 and 1866.

The width of the profile gradually increases if the Earth passes further away from the center of the trailet. Near the center is a core with a steep slope, which has a more shallow tail further out. The core is typical for the 1866, 1867, 1966, 1969 and 1999 profiles, while the profiles of 1998, 1965 and the second peak of 1999 are cases of further out. If we plot the width versus the distance to the trailet center (Y_o), as calculated by McNaught & Asher [5], then we find that Eq. 5 (solid line in fig. 5) indeed does fit the result. Note that the fit is not perfect, which suggests that individual trailet positions are uncertain by at least ±0.0001 AU.

However, the calculated trailet pattern (together making up the comet dust trail) is shifted outward by about +0.0003 AU. The curve in Fig. 5 should center on zero. We conclude that the Earth crossed about 0.0003 AU deeper into the debris trail ejected in 1899 than predicted. Unfortunately, that means that Earth will not cross quite as deep into the 1866 epoch trailet in 2001 and 2002, for which McNaught & Asher predicted peak rates of 10-35,000 and 25,000 respectively [5].

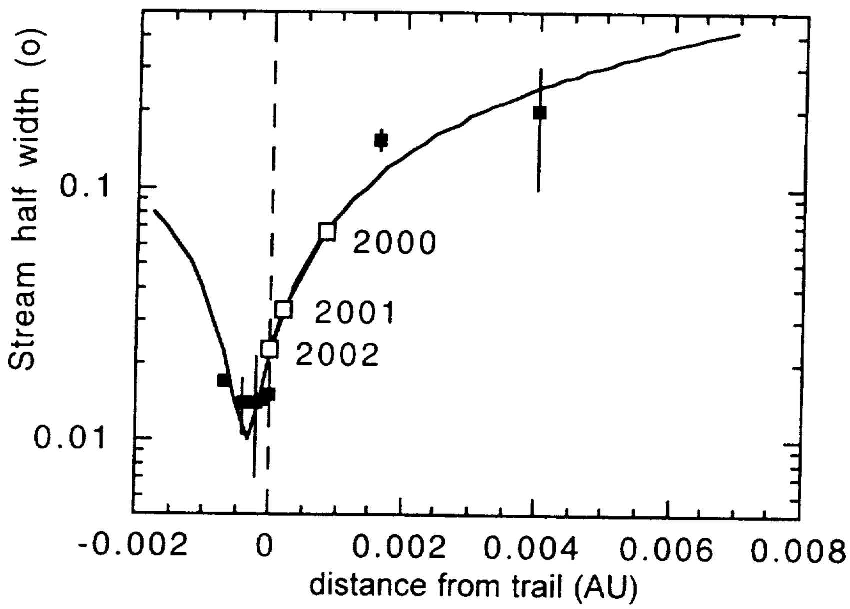

Fig. 5: The width of the profile as a function of distance from the center of the trailet.

On top of that are two more factors that influence the peak rate in future years: 1) the rate of decrease of dust density away from the comet for a pristine trailet of 1 revolution, and 2) the decay of dust density with each subsequent revolution.

Regarding (1), we have only the 1969 observations to base our discussion on (Fig. 6). For that encounter, McNaught and Asher [5] calculated a dead-center trailet passage through a mere 1 revolution trailet. If we adopt the shift of 0.0003 AU, then according to Eq. 6 the peak density at the trailet center would correspond to about four times higher rate than observed, i.e. ZHR =800. Similarly, we calculated the peak trailet density (in terms of ZHR) from all other storm and outburst profiles.

Furthermore, we assume that the dust density falls off inversely with the number of revolutions (N):

$$ZHR'_{max}\ (1\ rev.) = ZHR'_{max} \times N \qquad (7)$$

which is expected if the spreading is mainly due to differences in orbital period of the particles in the dust trailet. We also assume that all trailets are equal after 1 revolution. The result is shown in Fig. 6, as a function of mean anomaly (time after passage of the comet). Dark points at small mean anomaly are from IRAS observations of the comet Tempel 2 dust trail [6], scaled to match the Leonid shower data, to show how high the dust density might go up near the comet.

It is possible to predict the peak activity in 2000-2002 from the time since perihelion passage. Those moments are marked on the dashed line with an open square. The predicted peak rate follows from this by corrections according to Eq. 7 and Eq. 6. We find ZHR = 50 in 2000, ZHR = 50 in 2001 and ZHR = 40 in 2002 (1866 epoch ejecta only), whereby the width of the profiles should gradually decrease.

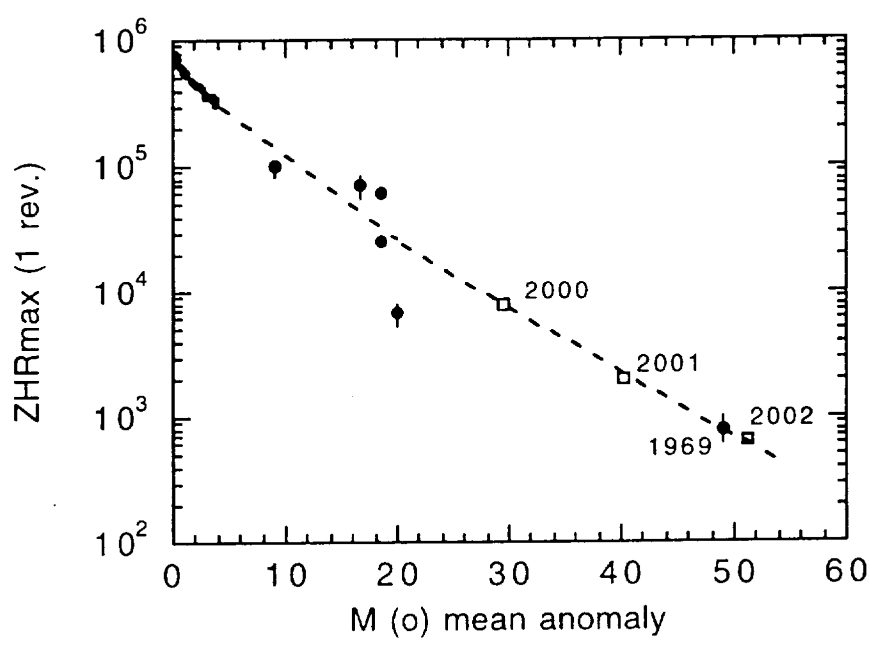

Fig. 6: Peak dust density in the trailet after 1 revolution, as derived from the flux profiles of past meteor storms and outbursts.

These would be Perseid like showers, no meteor storms, but with all the charm of meteor outbursts: a brief episode of high rates. Observations in Nov. 2000 will test the assumptions that go in the model and the predictions above. The next three years may help to measure how quickly the dust density falls off away from the comet and each encounter will be a strong test for refining the theoretical model.

The video record is a treasure of information that can be further analyzed. Unlike the hybrid visual-video observation technique, such in-depth analysis is time consuming and results are not expected for some time.

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